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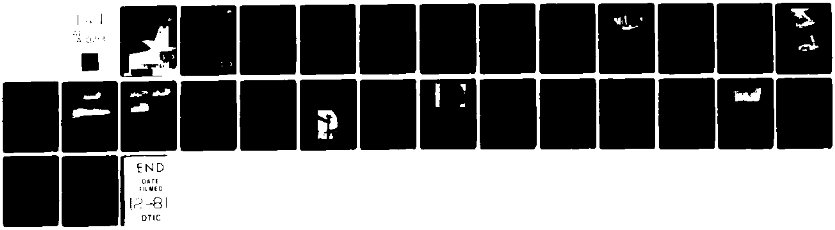

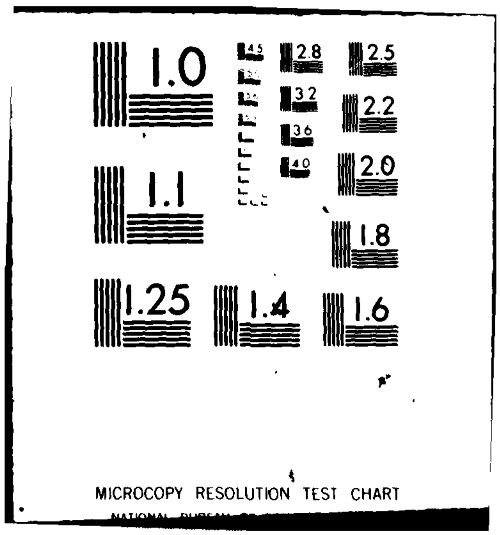
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Cold regions testing of an air-transportable shelter

Stephen N. Flanders

August 1981

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An air-transportable shelter designed and built at CRREL for use in cold regions underwent testing in Hanover, New Hampshire, and Ft. Greely, Alaska. The shelter demonstrated some of its capabilities for mobility by being towed for more than 60 miles behind various vehicles and by being transported on a C-130 cargo airplane, a CH-47 helicopter, and a trailer truck. The shelter proved to be very easy for a crew of two to four to set up in all weather conditions including -40°F cold. However, the gasoline-powered generator, which was a source for space heat as well as electricity, functioned very poorly. Overall, the prototype successfully demonstrated qualities of self-reliance, ease of operation and thermal efficiency.

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PREFACE

This report was prepared by Stephen N. Flanders, Research Civil Engineer, of the Civil Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this research was provided by DA Project 4A762730AT42, *Design, Construction and Operations Technology for Cold Regions,* Technical Area B, *Combat Development Support,* Work Unit E1/9, *Air-Transportable Shelter for Arctic Use.*

M. Dollahite of the U.S. Army Cold Regions Test Center and R. Adams of CRREL technically reviewed the manuscript of this report.

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ILLUSTRATIONS

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
inch	25.4*	millimeter
foot	0.3048*	meter
$foot^2$	0.09290304*	$meter^2$
pound (mass)	0.4535924	kilogram
ton (mass)	907.1847	kilogram
pound-force	4.448222	newton
inch-pound-force	0.1129848	joule
mile/hour	0.4470400*	meter/second
knot	0.5144444	meter/second
gallon/hour	0.003785412	$meter^3$/hour
Btu/hour	0.2930711	watt
Btu/hour $foot^2$	3.152481	watt/$meter^2$
degrees Fahrenheit	$t_{°C} = (t_{°F}-32)/1.8$	degrees Celsius

*Exact

SUMMARY

An 8- × 8- × 20-ft shelter, expandable on one side and designed for use in cold regions, underwent testing at the U.S. Army Cold Regions Test Center, Ft. Greely, Alaska, and at CRREL in Hanover, New Hampshire, during the winters of 1976 through 1979. The test results show that the mobility and/erecting/striking features of the shelter were very successful. Furthermore, the heating system which recovers heat from the gasoline-powered alternator set proved to be both effective and economical. The engine itself performed poorly.

Test results that demonstrated the shelter's mobility included:

- Easy self-loading onto a C-130.
- 10,000 miles of truck transport without damage.
- Successful airlift with CH-47 *Chinook* helicopter.
- Easy self-loading onto a truck bed.
- Self mobility on skis or wheels at low speed.

Erecting the shelter at −56°F with a three-man crew required

- Only 45.5 minutes of elapsed time.
- Only one-third the military criterion time per square foot of floor space.
- Removal of arctic mittens for only two momentary operations.

The shelter prototype proved to be thermally efficient by demonstrating

- Two to three times better insulating ability than comparable shelters.
- Excellent thermal comfort for occupants.
- Effective heat recovery from the generator set's gasoline engine.

The engine on the generator set proved to be unsatisfactory. The usefulness of the shelter depends on being self-reliant in remote locations for which the reliability of the alternator set for electricity and waste heat is essential. Unfortunately, the various control systems on the engine, most of them electrical, were prone to frequent failure.

Extensive testing demonstrated the merits of designing shelters specifically for use in extreme cold regions. The snow melter and water heater made efficient use of the engine's waste heat capacity. The shelter's qualities for habitation, reliability and load bearing capabilities also received scrutiny.

COLD REGIONS TESTING OF AN AIR-TRANSPORTABLE SHELTER

Stephen N. Flanders

INTRODUCTION

This report describes the testing of an air-transportable ISO shelter prototype designed and built at CRREL. ISO shelters conform to applicable International Standards Organization requirements for modular shipping containers in that they must be 8×8×20 ft and withstand heavy loads from other containers placed on top of them. The shelter has features specially suited for use in cold regions which promote 1) self-reliance, 2) ease of operation and 3) thermal efficiency. Flanders and Tobiasson (1981) and Flanders (1980) outline these features in greater detail. Previous hard wall shelters that the Army has used in central Alaska did not perform well in the harsh winter (Beavin 1975, Malone 1979).

Self-reliance means that a crew can unload, move and set up a shelter without resorting to separate specialized equipment. Previous shelters have required pallets and K-loaders (special roller-equipped adjustable trailers) for unloading from aircraft, fork lifts for unloading from trucks, and special mobilizers for moving the shelter from point to point. The CRREL prototype shelter has adjustable legs equipped with skis or wheels that obviate the need for these pieces of equipment. The cover shows the shelter being loaded onto a C-130.

Ease of operation is particularly difficult to achieve in exteme cold. A person wearing bulky winter clothing and large mittens cannot work as efficiently as his normally dressed counterpart. Previous shelters employed small, delicate fasteners for field connections and required precise fitting of pieces. Crewmen had to remove their arctic mittens for two out of three operations. The CRREL prototype requires only a few simple steps with little precision for erecting or striking. Field fasteners for the CRREL shelter are oversize bolts or pins that are easy to manipulate with large mittens. Figure 1 shows the shelter fully erected on site.

Thermal efficiency means more than conserving expensive fuel from limited supplies for heating shelters. It also means effective comfort control for shelter occupants. Previous shelters had very poor insulation which not only wasted fuel, but caused discomfort from uneven temperature distribution and inconvenience from condensation. The CRREL prototype has two to three times the insulating properties of previous hard wall shelters and employs effective seals against air leakage.

The CRREL prototype air transportable shelter for cold regions underwent three seasons (1976-79) of cold weather testing—one at CRREL in Hanover, New Hampshire, and two at the U.S. Army Cold Regions Test Center (CRTC), Ft. Greely, Alaska (Dollahite 1978 and 1979). The results of the testing showed the prototype's cold regions performance to be far superior to that of previous military shelters.

Figure 1. Fully erected shelter on site at Ft. Greely, Alaska.

DESCRIPTION OF SHELTER

A shelter can be expected to perform well in cold regions only if it is specifically designed and proven for use in extreme cold and remote locations. CRTC experience (Malone 1974 and Beavin 1975) with shelters designed principally for temperate conditions demonstrates that they can be very difficult to use in extreme cold and that thermal inefficiency has been a built-in drawback. As a result, the CRREL prototype was designed so it could function nearly as well in extreme cold as in temperate conditions.

The CRREL shelter is a 6000-lb box that serves as its own container during shipping and expands to provide additional area when occupied. An optional tent covers the expanded unit. Fully equipped, the shelter weighs 10,000 lb.

In the shipping mode the shelter is designed to conform with ISO air/sea/land container requirements for size (about $8 \times 8 \times 20$ ft), fittings and strength. The shelter has a flat, reinforced underside that allows air transport by military 463L cargo handling systems without benefit of pallets.

The basic container becomes a shelter when a hinged porch panel swings down to provide access to the front door. All the essential facilities (power, heat, kitchen, and bunk room) are available in the 128-ft^2 core module. The shelter expands to an area of 265 ft^2 in two stages. First, the roof and three walls extend out from the core module as a rigid structural unit. A floor then swings down inside the extended unit to form 137 ft^2 of additional space with the help of a block and tackle.

A nylon tent covers the entire expanded shelter, protecting the building, creating an arctic entrance through the porch, and permitting the 15×20-ft roof area to be used for storage or bivouac space.

The shelter has removable, adjustable legs that elevate the building to help prevent snow drift accumulation. These legs permit a crew to load or unload the shelter on military aircraft and vehicles without special equipment. The legs can be mounted on skis or wheels to permit slow towing for short distances.

The shelter roofs, walls and floors are foam core plywood panels. Aluminum, steel, and fiber-reinforced plastic (FRP) provide additional strength in areas subjected to additional loads during shipping.

The fixed portion of the shelter (see Fig. 2) contains a kitchen, a bunk room for four persons, a toilet, closets, an engine, and utility and snow melt compartments. There is a main entrance as well as an emergency exit from the bunk room.

An 8-kW liquid-cooled alternator set driven by a four-cylinder gasoline engine provides heat

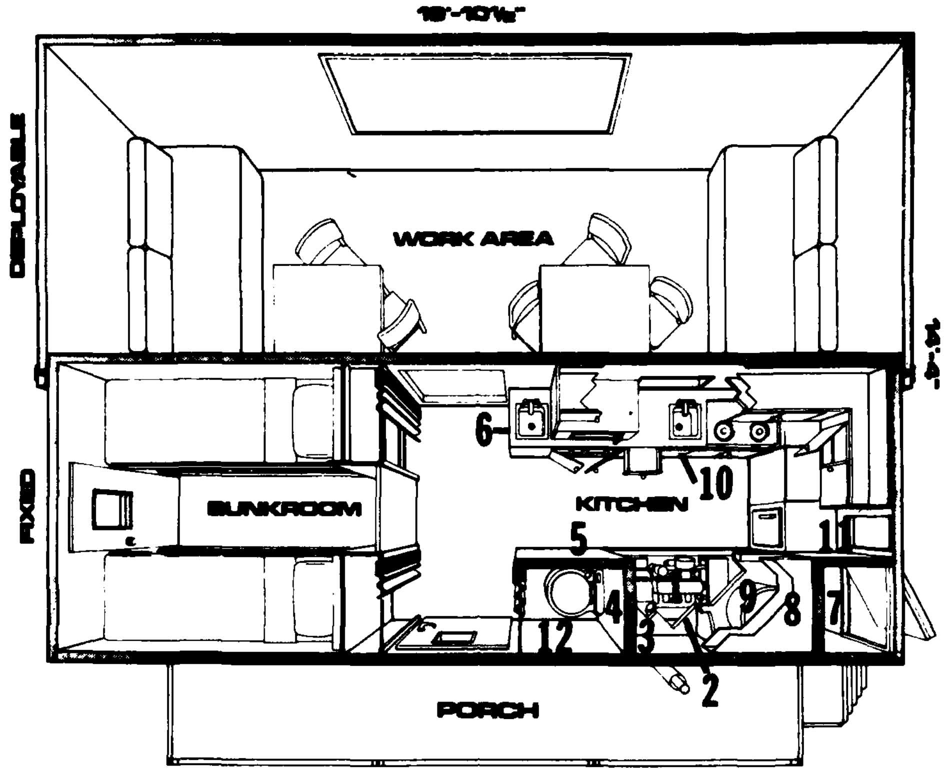


Figure 2. Equipment location.

1. *Alternator*
2. *Auxiliary heater*
3. *Battery charger*
4. *Electrical distribution panel*
5. *Remote start panel*
6. *Fan-coil space heater*
7. *Snowmelt/holding tank*
8. *Grávity tank*
9. *Water heater*
10. *Wastewater holding tank*
11. *Drinking water filter*
12. *Safety systems*

and power. The power is single phase 125-250-V a.c.

Waste heat from the engine is used in a number of ways. Engine coolant from the block and exhaust manifold circulates through a heat exchanger located in the central part of the building. A blower forces warmed air through a distribution network. Waste engine heat is also used to heat water and melt snow.

The generator should run only at times of peak activity to provide direct electricity and to charge the 12-V d.c. batteries. The batteries power the 12-V lighting system, an auxiliary gasoline fired heater, and a carbon monoxide monitoring and alarm system.

Safety systems include an automatic 12-V d.c. fire extinguishing system for the engine and heater compartments and a heat/smoke alarm.

The shelter has a waterproof receptacle outside on the porch that will accept 250-V a.c. 20-A line service. All receptacles inside and outside the shelter are ground-fault interrupted (GFI), except as labeled.

Two kinds of fasteners, bolts and locking pins, connect parts after reconfiguration. Bolts are interchangeable, ½-in. coarse thread (13 threads/in.) and 1½ in. long under the hex head.

TEST PROCEDURES AND RESULTS

The most important shelter capabilities that underwent evaluation during the winters of 1976-77 (at Hanover), 1977-78 and 1978-79 (both at Ft. Greely) were:

1. Mobility—long, medium and short distance

transport.
2. Erection/striking—establishment on site, hard wall and tentage.
3. Thermal efficiency—overall performance, component performance and heaters.
4. Habitation—with live-in crew.
5. Electrical generation—alternator set and standby batteries.
6. Safety—hazard detection and emergency exit.
7. Water supply—snow collection, snow melter, etc.
8. Component reliabilty—basic shelter, mobile undercarriage, equipment.

In addition, the shelter's structural strength received attention.

Mobility

We can consider three categories of distance for moving a shelter to its cold regions destination. Long-distance transport would be the means that brings the shelter to its nominal cold regions destination, e.g. Alaska, Greenland, Antarctica, etc. Intermediate-distance transport would carry the shelter from its point of entry to the shelter's nominal site, e.g. Ft. Greely, Alaska. Short-range transport would deliver the shelter to its exact location, e.g. observation point 8 at Fort Greely. The CRREL prototype shelter underwent tests of several means in each category.

Long distance transport

The three means of important transportation in this category are military transport aircraft, trailer trucks, and shipment as an ISO container.

The Lockheed C-130 Hercules is the military transport aircraft most likely to fly to remote airfields in cold regions. This aircraft accommodates up to 155,000 lb of cargo in a 41-ft-long × 10.25-ft-wide × 9.17-ft-high rectilinear compartment (AMC 1967). Therefore, the C-130 could carry two 20-ft ISO shelters with little space to spare, but with much additional load capacity.

C-130 aircraft incorporate a standard cargo handling system (called Dash 4A) which employs rollers to support and convey cargo together with guide rails. With the rollers in place, an empty C-130's cargo deck is between 47⅝ and 43⅝ in. above the ground.

A C-130D participated in an exercise at the Lebanon, New Hampshire, Regional Airport to demonstrate the CRREL prototype shelter's capability for loading without the aid of ground handling equipment onto the aircraft. The March 1977 exercise took place on pavement and the shelter was equipped with its wheels.

The procedure was as follows:

1. Align the bottom of the shelter slightly above the level of the aircraft rollers using the shelter's jack legs to adjust its height.

2. Overlap the end of the shelter on the tailgate and lower the legs until the shelter rests on the tailgate. Remove the first set of legs (Fig. 3).

3. Draw the shelter on further until the second set of legs reaches the end of the tailgate, and then remove them (Fig. 4).

4. Roll the shelter into place in the aircraft, secure it and secure the legs on the tailgate to await extraction.

This procedure with a crew of four required 22 minutes to roll the shelter by hand into position on the aircraft, ready for securing. Time was limited, so the loadmaster omitted actually securing the shelter inside, which he estimated would take about 20 minutes of routine work. Extraction required 24 minutes for the same crew. The loadmaster said it was the easiest non-palletized item he had ever loaded.

Current ISO military shelters, unlike the CRREL prototype, do not have a smooth bottom that makes loading onto the aircraft roller system possible without pallets. Most significantly, these shelters require either K-loader trailers or special mobilizers, neither of which might be available for the mission.

Surface transport is usually less expensive than air transport. For that reason, the CRREL shelter prototype traveled on a trailer truck for one and one-half round trips between Hanover, New Hampshire, and Ft. Greely, Alaska, approximately 10,000 total miles.

Each leg required two loading/unloadings because of a change of carriers. For the sake of speed, forklifts were the usual means of unloading. The shelter sustained no damage from either transportation or handling.

The most constraining design feature of the shelter, its qualities as an ISO container, never underwent meaningful testing. Current ISO shelter designs meet the pertinent standards with difficulty. Actual ISO shipping containers in continuous world-wide service are a lot sturdier than either the CRREL prototype or current military shelters. The prototype did not undergo testing because of possible damage if failure occurred before the load could be withdrawn.

Intermediate distance transport

There are two significant means in this category, helicopters and stake-body trucks. The

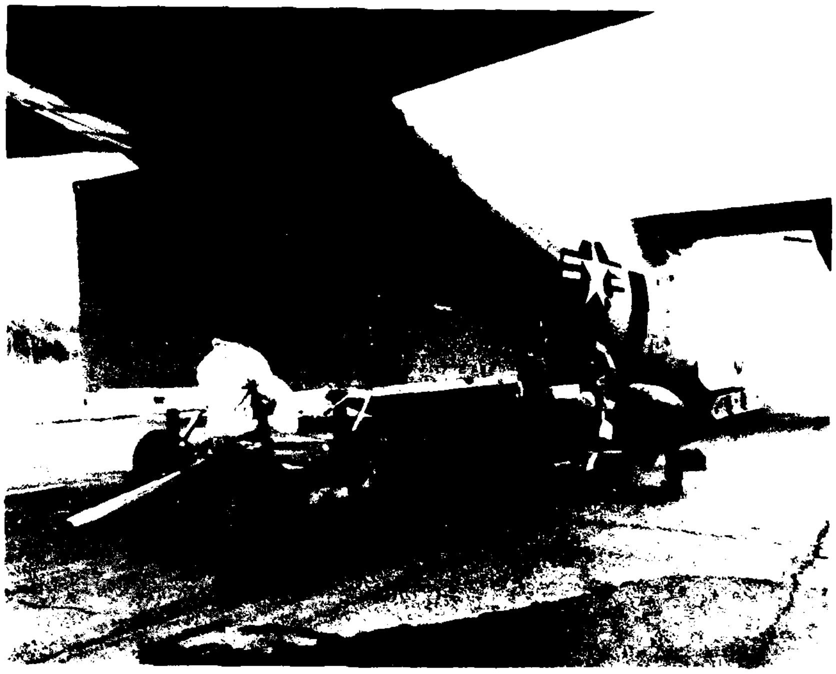


Figure 3. Shelter loading on C-130—first set of legs removed.

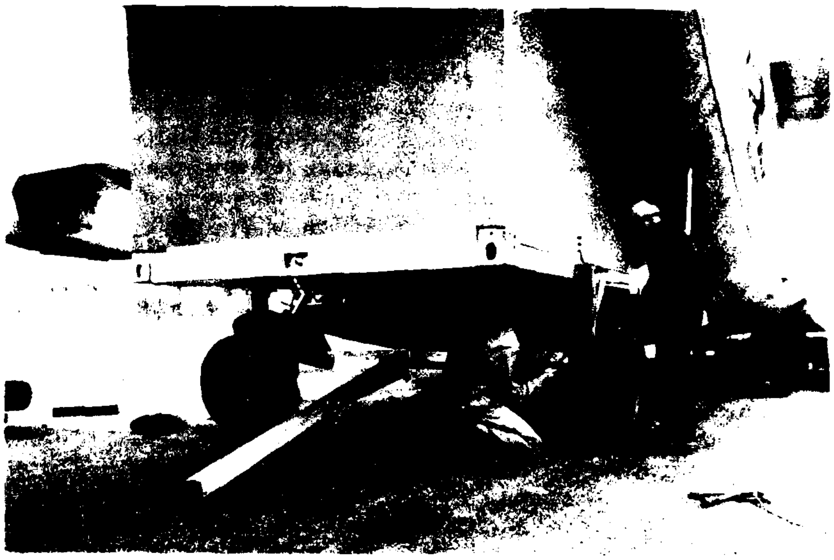


Figure 4. Shelter on C-130—removing second set of legs.

Boeing-Vertol CH-47 *Chinook* is the most widely available helicopter capable of slinging an ISO shelter. Its sling load capacity is 16,000 lb or more, depending on the model (AMC 1967). A CH-47C participated in an exercise at Allen Army Airfield, Ft. Greely, to demonstrate the CRREL prototype shelter's capability for helicopter airlift. The March 1978 exercise involved rigging the shelter, and testing it for hover and flight stability through a series of maneuvers.

The rigging of the shelter for airlift employed ten 20-ft cargo slings of 10,000 lb capacity each

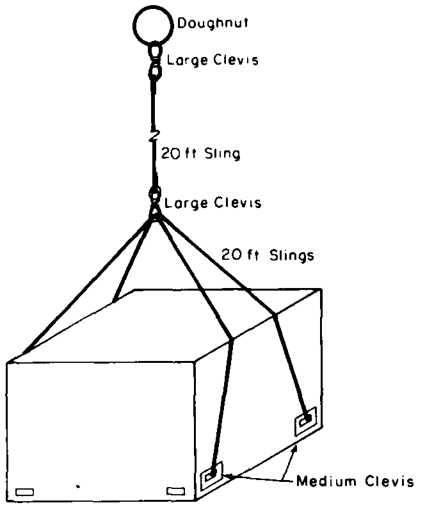


Figure 5. Sling rigging for the helicopter lift.

and miscellaneous items shown in Figure 5. A ground crew of three pathfinders rigged the shelter and hooked it to the hovering helicopters. Two were on the roof of the shelter and one held an aluminum ladder to provide escape when the hookup was complete. An alternative procedure is for the crew chief of the helicopter to reach a retrieving hook through an access door and secure the doughnut to the cargo hook. A grounding probe was an important part of the equipment, particularly in the Alaskan winter, because a substantial static charge can accumulate on the helicopter.

In hover, shown in Figure 6, the shelter rotated about its vertical axis. In forward flight the shelter flew fore-and-aft oriented until the helicopter executed a descending turn; thereafter it rotated and flew broadside to the direction of flight. The helicopter crew recommended a maximum airspeed of 80 knots for transporting the shelter. In sum, the flight crew considered the shelter to be very stable in straight and level flight and suitable for helicopter airlift (Dollahite 1978).

Most other shelters of the ISO container shape fly stably (Malone 1974 and Beavin 1975). However, one 50-ft expandable unit with a 32-in.-wide ×13-ft-long transport configuration oscillated on a 12-ft sling at speeds of more than 30 knots. Oscillation did not occur until 50 knots when varied length slings and a drogue parachute were part of the equipment (Malone 1974).

In addition to helicopter conveyance, intermediate transport of a shelter might involve a locally procured stake-body truck. However, the dimensions of the standard 2½-ton Army truck bed are incompatible with the ISO container dimensions.

A commercial truck with its sides removed on an 18-ft bed participated in an exercise to evaluate the shelter's capability for self-loading on such a vehicle. It was evident that the truck's bed would be too high for the shelter's 55.8-in. maximum leg extension capability, so a tilt bed capability was necessary for successful loading.

The procedure for loading the truck was similar to that for the C-130. However, the truck had no built-in roller feature, so 8-ft lengths of 1¼-in. iron pipe served instead. Because the shelter had to roll uphill on the bed, cable winches substituted for the hand pushing used on the C-130. Figure 6 depicts the loading sequence which took about 20 minutes.

The shelter's adjustable legs and wheels can eliminate the need for forklift trucks or the use of a wrecker which might not be available at a remote location. One ISO shelter tested by the CRTC sustained slight damage when it swung against a 5-ton wrecker during unloading from a truck (Malone 1974).

Short distance transport

The CRREL shelter has a built-in towing capability to avoid employing a large truck and a lifting apparatus for a short trip. The wheels or skis should permit movement over fairly smooth terrain. It tows from either end, since four-wheel trailers are very difficult to back up.

The shelter was towed approximately 62 miles during the two winters at CRTC. About six of the miles were with skis. The towing vehicles were 1) a 2½-ton cargo truck (M35A1), 2) an armored personnel carrier (M113), 3) a 5-ton wrecker (M543A2) and 4) a ¼-ton truck (M151A1). The usual terrain consisted of single-lane gravel roads. The unplowed roads had 4 to 6 in. of snow.

The results of the tests were more favorable in the first of the two winters. In the first year the test team felt that 10 mph was a suitable speed on amply wide plowed roads, but in the second year they reported that 4 mph was an appropriate maximum for narrow roads to assure reliable towing of the shelter.

A failure of the undercarriage occurred while towing early in the second season. A steering-rod end broke and allowed a wheel to turn outwards unrestrained. This damaged a diagonal brace. The test crew removed the brace from the leg to bring the shelter back to the shop. This leg then

Figure 6. Helicopter flight test of the CRREL shelter at Ft. Greely, Alaska.

sheared its attachment bolts and caused damage to several undercarriage parts.

The accident was a probable result of a mishap that occurred during the modification of the shelter. A workman placed a pair of bolts in the holes that disenable the steering. Normally a pair of pins either connects the steering parts or locks steering, but not both at the same time. When the shelter received a tow from a large front-end loader, other parts of the steering mechanism broke, but the steering-rod ends held. It is likely that the incident weakened them so that one failed during CRTC testing.

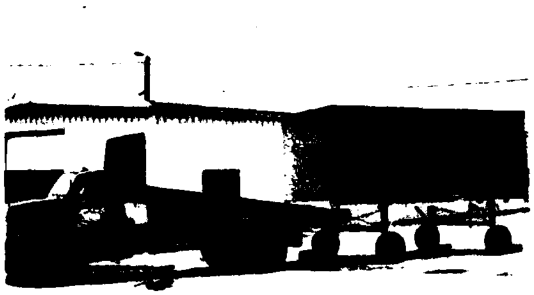
During the first winter the skis permitted the shelter to wander from side to side. Test personnel judged 5 mph to be a safe maximum speed for skis. Shims in the legs to eliminate play and a ridge running down the center of the ski were installed to control the wandering; however, the test team did not judge conditions to be suitable for trying the skis in the second year.

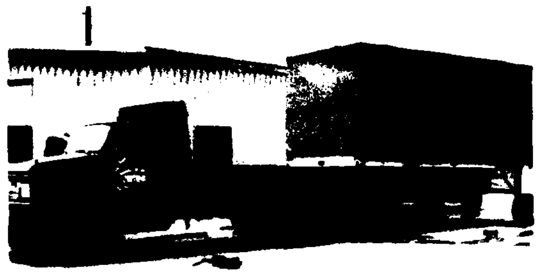
Dragging is the method for short-range transport of other shelters when a forklift truck is unavailable. CRTC personnel have pulled these other shelters over bare, rocky ground with no visible damage to the shelters' undersides. However, a more reasonable means of transport would have eliminated the extreme efforts required to make the underside of the shelter sufficiently durable.

Ease of erecting and striking

There are three basic stages to erecting or striking the CRREL prototype shelter:

1. Establishment on site—positioning, installing footing pads and leveling
2. Expanding hard wall portion—employing expansion hardware, all-roof assembly and floor
3. Erecting tentage—using attachment points.





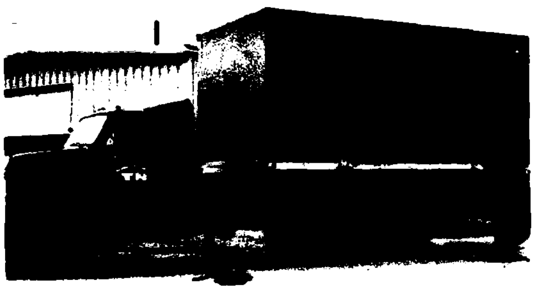


Figure 7. Loading the shelter onto a truck.

framework, doors and tentage.

Striking the shelter occurs in the opposite sequence.

The shelter prototype underwent 32 expansion/striking cycles during the two winter seasons at CRTC. The method for testing the shelter's ability to perform these functions was similar both winters. The crew size was typically four the first year and three the second. Each winter the crew received training in a heated hangar.

Three expansion/striking exercises each winter were timed. The timed exercises in the first winter were not consistent procedures, but did include erecting the tentage. Those in the second winter followed a prescribed check list, but involved the hard wall portion only. The objective was to record the elapsed time for each procedure, the productivity of the participants and any difficulties they experienced, especially the need to remove arctic mittens.

The criterion time for striking or expanding a shelter the size of the CRREL prototype was 6.6 man-hours based on a requirement for 4 man-hours per gross 160 ft² (U.S.A. TRADOC 1974). Under the worst conditions—when the shelter was covered with a glaze of ice—the crew was able to expand the shelter twice as fast as required. At -56°F the crew was able to do almost three times better than required.

Expansion

Figure 8 shows the results of the six timed hard wall expansion exercises. The first bars in the figure depict the elapsed time necessary to lower the porch, install the footings, and level the shelter in the survival mode (the configuration for use with the least preparation). The end of the bar depicts the elapsed time for expansion of the shelter in each case. Both the shelter and the method of testing underwent improvement over the summer between exercises 3 and 4. The dashed segments of the bars show the elapsed time necessary to install the skis. This step was reportedly unduly time-consuming because of an awkward detail in the auxiliary jack.

Exercise 3 was the only expansion test in the first year at CRTC that involved installing the skis, an operation that required only eight minutes. (An auxiliary jack permitted retracting each leg to install or remove skis.) In tests 4-6 during

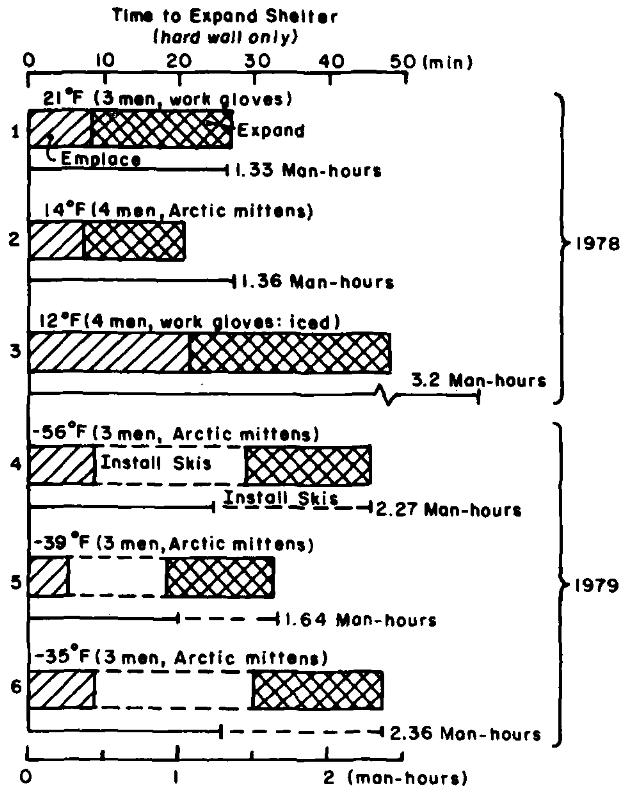


Figure 8. Time to expand the hardwall portion of the shelter. The dashed portions show the time necessary to use the auxiliary jack.

the second year this step required from 13 to 21 minutes. The jack used for ski installation required participants to remove their arctic mittens to unpack it and did not have sufficient continuous adjustment to accommodate soft terrain without clearing of undergrowth or moving the discrete gross adjustment mechanism several times. Improvement of this jack should be both easy to accomplish and speed up the procedure significantly.

Only two steps in the process required removal of arctic mittens. One was unpacking the auxiliary jack. The other was detaching the floor hoist from the floor of the extended unit which swings down from being stowed along the wall. Better design should eliminate the former problem. The latter step required only 8 to 22 seconds and does not warrant finding a substitute for the compact nautical clevis attachment solely to facilitate using arctic mittens.

Glazing the shelter with ice doubled the time required to expand it (see exercise 3 in Fig. 8). The need to chip ice from bolt heads and from within sockets to permit the use of tools impeded progress. Expanding the shelter, which normally takes from 30 seconds to 3½ minutes, required more than 12 minutes when it involved limbering up of an exposed seal protecting the roof joint between the fixed and extended portions of the shelter. Since this seal was redundant, it is now absent to prevent repetition of this problem.

Striking

Striking the shelter required similar times as expansion. The connections were only slightly easier to undo than to fasten. For example, a worker still had to turn a bolt to loosen it, but he didn't have to align the threads when withdrawing it.

Figure 9 shows that the stage of removing the skis was unduly time-consuming, as was their installation. Icing did not impede striking the hardwall portion of the shelter because the ice was

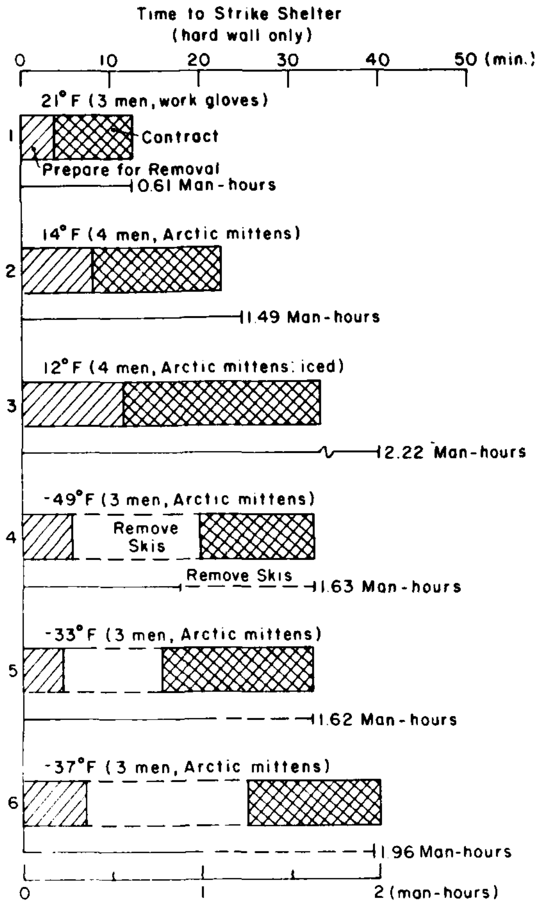


Figure 9. Time to strike the hardwall portion of the shelter. The dashed portions show the time necessary to use the auxiliary jack.

applied with the tentage in place.

The stairway was somewhat difficult to remove and stow when test personnel were wearing arctic mittens. The main difficulty was using the buckles provided with the straps to secure the stair in the shelter. However, this step required only 1½ to 2½ minutes and could be streamlined with the use of the link and latch attachments found on the straps elsewhere in the shelter.

Tentage

Erecting or striking of tentage was much more time-consuming than the same procedure for the hardwall shelter portion of the CRREL prototype. Whereas the hard wall portion required approximately 0.46 man-minutes erection time per square foot, the tentage required about 0.82 man-minutes. This is still about twice as fast as the 1.5 man-minute/ft^2 required operational capability (ROC) *criterion* (U.S.A. TRADOC 1974) would require for hard wall shelter expansion. In only the second of the timed exercises shown in Figure 10 did the time to erect the tentage exceed the 4.7-man-hour ROC criterion. Exercise 2 involved the use of arctic mittens which slowed the crew down considerably more than in exercise 3, involving the shelter glazed with ice.

The main impediment to rapid progress was the use of large wire pins (Fig. 11) that had to be inserted in close-fitting holes, sometimes from arm's length. During the summer between CRTC winter tests these holes were enlarged to diminish the requirement for good alignment. The fabric was quite difficult to secure along its hem to the edge of the building roof even when arctic mittens were not used.

Striking the shelter tentage was much faster because it was much easier to disconnect the fabric and unpin the tent structure than to emplace the pins. Icing the tent had only a small effect on the time required to strike it.

The test crew expanded the hard wall portion of the shelter in winds of 25 knots gusting to 30 knots. Under these conditions, they judged the wind to be too strong for erecting the tentage. Therefore windy conditions or extreme cold should prompt the shelter's crew to wait for favorable weather for efficient erecting of the tentage.

Thermal efficiency and performance

During the CRREL prototype shelter's two stays at CRTC it underwent several different tests for thermal efficiency and performance. These included an overall appraisal of its temperature response to warming and its total resistance to heat loss. Spot investigations of individual panels corroborated the results of the overall tests. Tests also evaluated the performance of the primary and auxiliary heaters.

Overall thermal efficiency—the basic thermal performance of the shelter—received scrutiny in four ways: 1) measuring the rate of heating and cooling, 2) determining stratification, 3) infrared inspection, and 4) heat loss measurement.

Heating and cooling rate

The rate of warming the shelter is a function of the initial temperature regime inside the shelter, the diffusion constant of the shelter and its contents, the outdoor ambient temperature and the output of the heater warming the shelter. Experiments demonstrated the ability of the onboard heaters to warm the shelter.

At an average outdoor ambient temperature

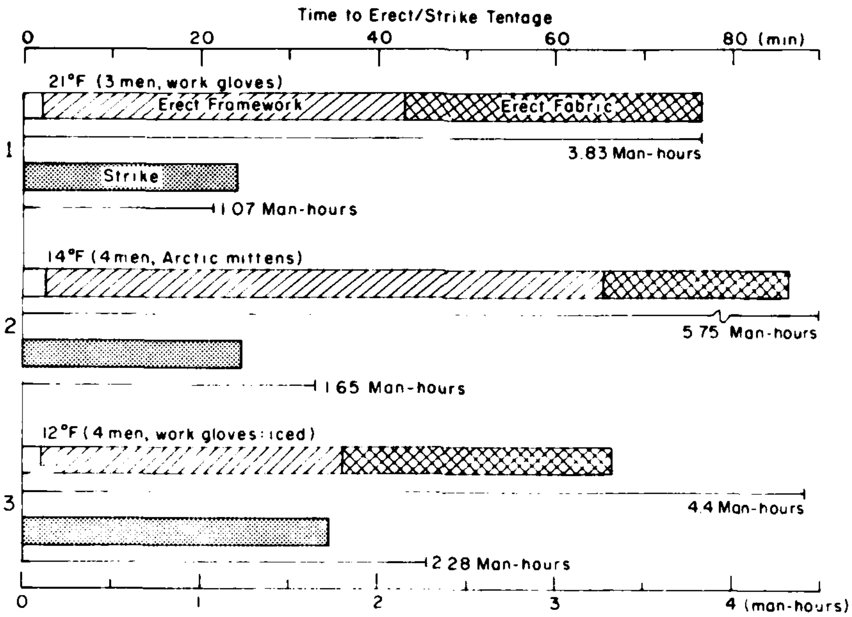


Figure 10. Time to erect and strike the tentage.

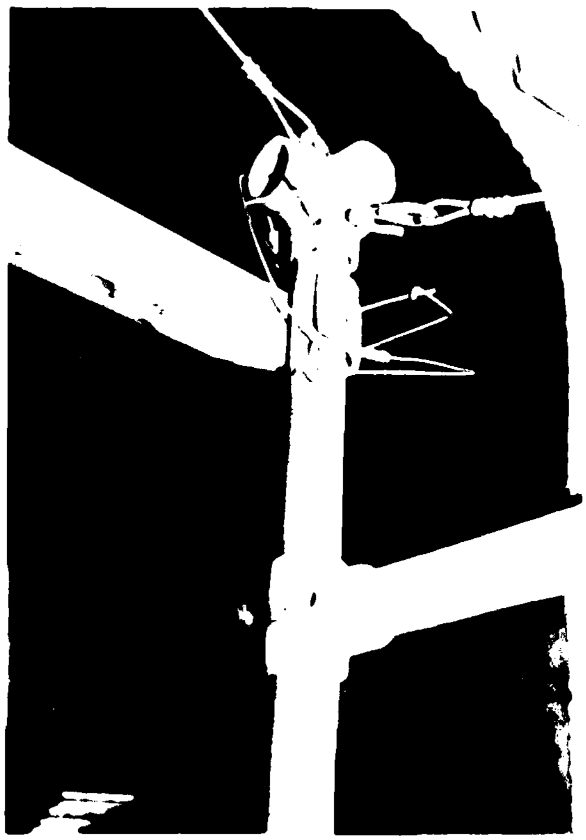


Figure 11. Typical tentage pin connection—until the holes were enlarged it was difficult to align the pin with holes.

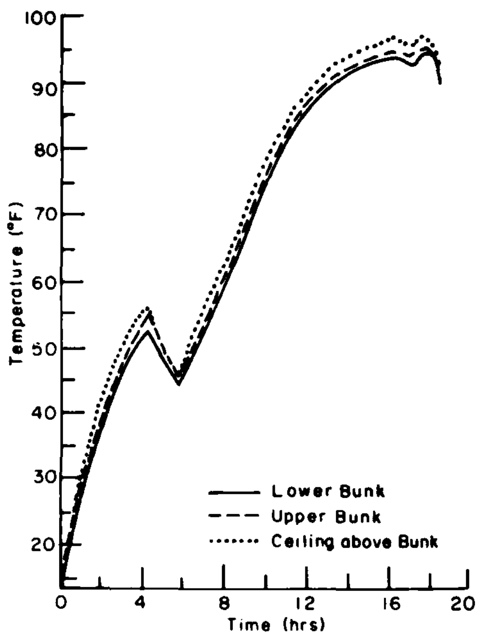


Figure 12. Rate of warming inside the shelter with the primary heater only.

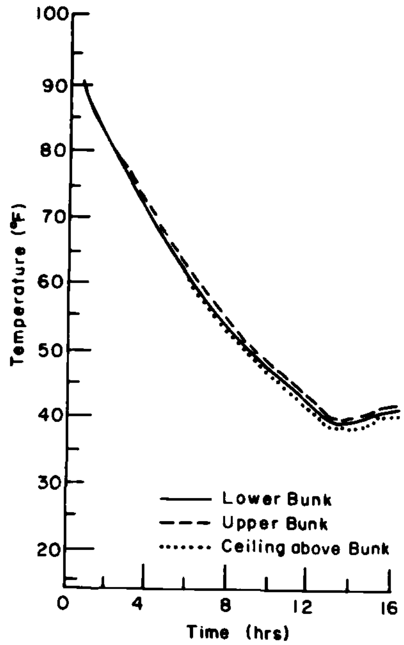


Figure 13. Rate of cooling inside the shelter with no heat input.

of around 0°F, the shelter warmed to 68°F from 14°F at an average rate of about 9°F/hr using the primary (heat recovery) system only (Fig. 12). With the additional help of the auxiliary heater, the rate of warming was about 14°/hr when the outdoor ambient temperature was around 20°F

The auxiliary heater by itself would not contribute a very fast warming rate but was capable of maintaining a temperature difference of 75°F in the kitchen area and 36°F elsewhere. This can protect against freezing in an unattended structure.

The data in Figure 13 show that, when the shelter is allowed to cool, the temperature difference between indoors and out (ΔT in °F) at time t (in hours) conforms to the expression

$$\Delta T(t) = \Delta T(t_0)\, e^{-0.062t} \tag{1}$$

About 12 hours is required for the inside temperature to drop from 68°F to the freezing level after the heat has been turned off with outdoor ambient conditions around 0°F.

Stratification

The thermocouple instrumentation during the tests demonstrated that the temperature distribution throughout the shelter was very uniform despite an indoor/outdoor temperature difference of 100°F when the main heating system was running. Temperature distributions between floor and ceiling and place to place varied by only 2° or 3°F. It appears that the air distribution system and the ample insulation were very effective in eliminating stratification of air and cold spots.

Infrared inspection

Thermograms of the shelter, such as in Figure 14, demonstrated that the surface temperatures do not vary by more than 1.8°F at a ΔT of about 32°F. Inspection from all sides revealed no heat leaks except around the engine compartment door which was open for the operation of the generator and the snow melter which is a source of warm water vapor.

Thermal properties of panels

Spot measurements with temperature and heat flux sensors of the thermal resistance of shelter wall, floor and roof panels over a period of 12 hours corroborated the theoretical design calculations shown in Table 1.

This good agreement between calculated and measured values resulted in an expected average R-value of about 12 for the panels. The extruded polystyrene foam insulated plywood sandwich panels of the CRREL shelter prototype

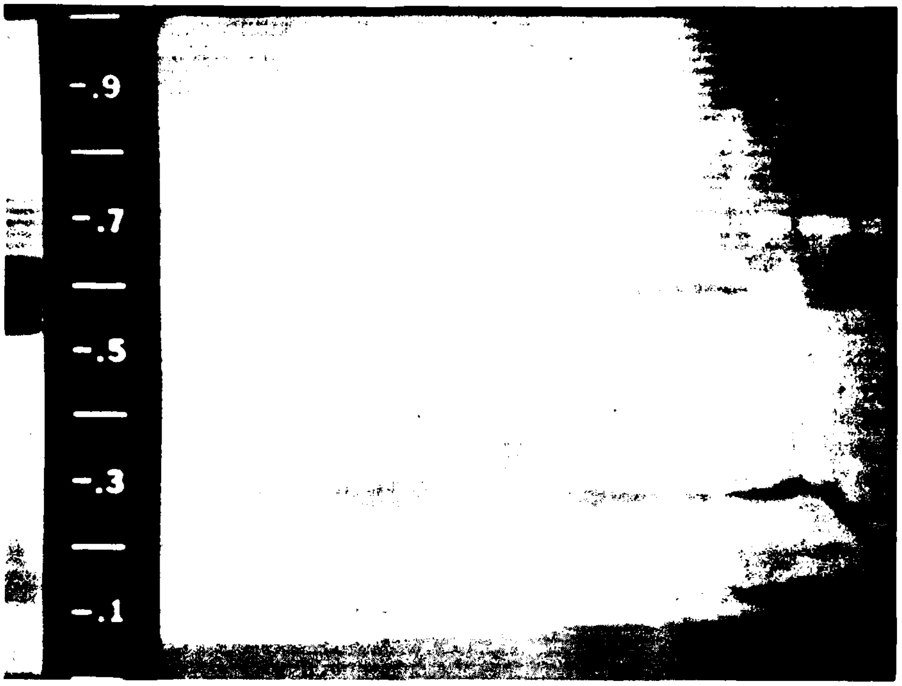


Figure 14. Thermogram of the shelter at ΔT = 32°F.

Table 1. Measured vs calculated R-values of selected locations on the exterior surface of the CRREL prototype shelter.

Location	*Measured*	*Calculated*
1. 2-in. wall at stud	2.6	2.7
2. 2-in. wall between studs	8.1	8.3
3. 3-in. roof at joists	5.6	4.5
4. 3-in. roof between joists	15.8	15.9
5. 7-in. floor between joists	37.0	35.7

compare very favorably in thermal performance with uninsulated honeycomb panels of current military shelter designs. The CRREL panels have R-values of 8.1 and 15.8 for 2-and 3-in. thicknesses, whereas the honeycomb panels have R-values of only 4.6 at 2 in. and 5.7 at 3 in. Therefore, the average thermal performance of CRREL panels is about double that of current military designs.

Heat loss measurement

Fifteen hours of data on indoor and outdoor temperatures and the electrical power consumption necessary to maintain a fairly constant indoor temperature yielded an apparent overall U-value of 0.059 BTU/hr ft^2. This value is equivalent to an average R-value (1/U) of 17 with the effects of air leakages and window heat loss, as compared with an expected overall value of R = 12 for the panels alone. This result may reflect some experimental error: available electrical capacity limited the test to only two of the five resistance heaters in the shelter and provided a ΔT of 43°F. This temperature difference, although adequate, was not as great as desired to overwhelm extraneous influences. This 15-hour test reportedly started about two hours before sunset in March (Murrell 1979). Therefore, solar radiation may have been a small additional source of heat gain. Additionally, the 43°F ΔT would not have induced air leakage very strongly. CRTC records are not clear on these particulars.

The tentage was in place during this thermal testing and could have made a genuine contribution to thermal performance. It can trap slightly warmed air above the shelter roof and diminish

air leakage.

Heat output

The fan-coil heat recovery unit that constitutes the primary source of space heating and the gasoline-fired auxiliary heater received an informal evaluation of performance. Gasoline consumption was 0.5 to 0.8 gal/hr for the alternator set and 0.16 gal/hr for the auxiliary heater. The CRTC data for use of the recovered heat from the generator level off at a maximum ΔT of 90°F. The auxiliary heater reportedly maintained an average ΔT of about 60°F at an outdoor temperature of about -17°F (Dollahite 1978).

The steady-state ΔT values for the two heaters are in about the same proportion as their rates of warm-up apparent in Figure 11:

$$\frac{\Delta T_{gen} + \Delta T_{aux}}{\Delta T_{gen}} = 1.7$$

and

$$\frac{d(\Delta T_{gen} + \Delta T_{aux})/dt}{d(\Delta T_{gen})/dt} = 1.6. \tag{2}$$

If we assume that the auxiliary heater is 75% efficient, then the observed output of the fan-coil unit from the alternator set is approximately

$$20{,}000 \text{ BTU/hr} \times 0.75 \times (90°\text{F}/60°\text{F})$$

$$= 22{,}500 \text{ BTU/hr}. \tag{3}$$

This value compares with the 55,000 BTU/hr advertised by the manufacturer of the alternator set as being the maximum available waste heat. Of course, the fan-coil unit distributes heat much more uniformly than the auxiliary heater.

A conservative estimate of the total heat loss from the shelter at steady state with a ΔT = 110°F would be about 12,100 BTU/hr. This reckons heat loss from the panels to be about 72% of the total, windows about 10% and air leakage 18%. This leaves more than 27,000 BTU/hr additional main and auxiliary heater capacity for warming the shelter. In practice, when the heaters were running properly, they offered ample capacity at the cold temperatures that the shelter encountered.

A secondary function of the auxiliary heater was to preheat the gasoline engine on the alternator set for easier starting after a cold soak. Unfortunately, the auxiliary heater did not run well after a cold soak of its own battery below 0°F, although the heater shared the compartment with the battery powering its pump and ignition so that waste heat would warm the battery. The heater did not start after cold soaking at temperatures below -20°F for 96 hours. Furthermore, the auxiliary heater did not have sufficient capacity to warm a cold-soaked four-cylinder gasoline engine from subzero temperatures rapidly.

More work in the key problem of supplying heat to a shelter in cold regions is necessary because of the inherent wastefulness of standard heaters for shelters, the unreliability of the generator set used in the CRREL prototype and the inadequacy of its auxiliary heater.

Electrical system

The shelter's self-reliance centered on its gasoline-powered generator set for both electricity and heat. This proved to be very unreliable in extreme cold weather. The electrical distribution system and its capability for connecting to an outside source were entirely satisfactory. The 12-V d.c. battery-powered back-up system was not always sufficient to power essential equipment at temperatures below 0°F.

Dollahite (1978-79) outlines many failures of the generator set. The most important categories of the problem were 1) electronic control circuitry, 2) hose connections for fuel and coolant, 3) exhaust icing, and 4) assorted mechanical problems.

The electronic control circuitry caused the first problems. Printed circuits with soldered-on transistors, resistors, diodes, etc., control most functions of the generator set including the choke, throttle, built-in preheater and various limit functions monitoring the health of the unit. Key electrical components failed, perhaps from dissimilar thermal expansion due to extreme cold followed by engine operating temperatures. This would cause poor engine performance and possibly contribute to mechanical problems thereafter.

Hose connections were a frequent headache. Metal fuel line attachment points shrink in cold more rapidly than the neoprene hoses so that leaks result. Tightening the hoses tends to fracture them in the cold and leaks persist. Copper lines replacing the neoprene worked satisfactorily.

Coolant lines, also of neoprene, functioned more satisfactorily. However, the PVC and polyethylene connectors that formed elbows, tees and nipples deteriorated with engine coolant

temperatures running around 220°F. Eliminating elbows or replacing plastic fittings with metal solved such problems.

The original exhaust configuration caused icing that drastically impaired engine performance. The exhaust system consisted of an 8-ft copper pipe that went above the engine and auxiliary heater compartments through the roof of the tentage. This pipe condensed moisture from the exhaust gas which accumulated and froze inside the pipe, restricting flow. Flexible exhaust hose directed down through the porch and away from the prevailing wind solved this problem.

The alternator set failed both test seasons beyond the capability of CRTC's well-equipped maintenance facility to repair it. After the first season the alternator set was returned to the factory at the manufacturer's expense for refurbishment. The manufacturer never submitted the requested analysis of why the unit failed or what required replacement.

Experienced people at CRTC felt that many of the problems with the engine were inherent to the operation of internal combustion engines in extreme cold. Standard military generator sets are more reliable, but not totally trustworthy. They are air-cooled, which makes heat recovery less safe and efficient than that from the water-cooled unit in the CRREL prototype shelter.

Habitation

Because the generator set proved so unreliable during both test seasons at CRTC, the shelter was occupied for only a total of 70 man-days, usually by three people. Although the shelter was designed for four occupants, three was the maximum number that the test participants felt could be accommodated without crowding. The participants' opinions, collected in a questionnaire form, were favorable to the shelter. They commented that the heating system was excellent when it was operational.

The results of the questionnaires come from three participants for the 1977-1978 test and five for the 1978-1979 test (Dollahite 1978 and 1979). They indicate the shelter was between "extremely good" and "moderately good" in the following qualities: 1) overall comfort and comfort near various surfaces and sources of heat, 2) noise level, 3) lighting for reading, writing and housekeeping, 4) housekeeping ease, and 5) use of doors. They rated the shelter between "very good" and "moderately good" for the following: 1) head room, 2) living space, 3) fresh air ventilation, 4) lack of drafts, 5) heat distribution, and 6) electrical outlet placement. The shelter was only "moderately good" to "not quite adequate" for providing lighting in the engine and utility compartments. It received no overall ratings of "not quite adequate" or worse. But there were several comments on possibie improvements of various details.

Safety features

The three most important safety features of the shelter are 1) capability for rapid emergency egress, 2) equipment for fire detection and extinction, and 3) a means of detecting carbon monoxide.

Emergency egress

The bunkroom is the only space in the shelter with its own emergency door. All other spaces are most accessible to the front door. Both doors open inward to facilitate clearance with panels on the outside and to prevent the wind from catching them. The four occupants should be able to overcome the danger of crowding next to the door, conflicting with opening it.

The CRTC tests for ease of exit involved stationing the participants in various positions in the shelter and sounding an exit alarm. The participants were dressed and expecting evacuation. Their exit times ranged from 7 to 11 seconds as shown in Table 2.

It is not clear how much time an emergency would require for safe evacuation or how much additional time unsuspecting occupants would take. Potentially the most hazardous fire would be from gasoline in the engine or auxiliary heater compartments. Walls contain these hazards which otherwise are adjacent to the main exit.

Fire

An automatic fire detector and extinguisher guards the engine and auxiliary heater. When the temperature in either compartment goes above 300°F or when someone activates a handle, the ignition systems for both the heater and the engine are deactivated, an alarm sounds and CO_2 deluges both compartments.

This automatic system went off for unknown reasons not related to fire during the first test season at CRTC. A second CO_2 portable fire extinguisher is available for other fires. A smoke detector in the toilet compartment supplements the fire warning system. The test button indicated that the smoke detector was operational

Table 2. Emergency exit data.

Trial no.	Personnel positions	Escape route	Time required for exit
1	Four personnel in bed in bedroom; covered with sheets and blankets.	All personnel exited through outside bedroom door.	7.0 seconds
2	Four personnel in bed in bedroom; covered with sheets and blankets.	All personnel exited through inside bedroom door, out shelter front door, then two out the stairway porch door and two out the opposite porch door.	10.0 seconds for the two who used the stairway porch door; 11.0 seconds for the opposite porch door.
3	Four personnel in bed in bedroom; covered with sheets and blankets.	All personnel exited through inside bedroom door; through shelter front door, then through stairway porch door.	10.0 seconds
4	Four in deployable section; two each on couches on opposite ends of deployable section.	All exited through shelter front door, then two out stairway porch door and two out opposite porch door.	7.0 seconds
5	One in bedroom covered with sheet and blanket; one in kitchen, one in deployable section on couch; one in utility compartment on portable toilet.	One out outside bedroom door; three out shelter front door, then two out stairway porch door and one out opposite porch door.	9.0 seconds
6	Four in bedroom in bed, covered with sheets and blankets.	All out inside bedroom door, then out shelter front door, then out stairway porch and one out opposite porch door.	9.0 seconds
7	Four in bedroom in bed, covered with sheets and blankets.	All out inside bedroom door, then out shelter front door, then out stairway porch door.	10.5 seconds.

during both winters at CRTC.

Carbon monoxide

CO was a frequent problem while running the alternator set during the first season of testing at CRTC. The poorly running engine appeared to be the source. Inadequate sealing of the engine compartment from the shelter interior permitted unhealthy indoor CO levels.

Refurbishing the engine and conscientious sealing of all passages between the engine compartment and the living space prevented any CO problems during the second test season. However, the CO detector gave frequent false alarms at CO levels between 10 and 35 ppm, well below the 50 ppm criterion level. Technicians felt that the calibration instructions were inadequate, so that it is unclear whether calibration was the sole problem or whether cold was a factor in its performance.

Experience with these safety systems indicates that the primary system may not function when needed. A simple, reliable back-up system, such as the disks that change color in the presence of CO, would be recommended.

Water system

The water system consists of four principal stages: 1) collection, 2) melting of ice or snow, 3) storage and distribution, and 4) disposal.

Water collection is particularly difficult when snow or ice is the source. Shoveling snow from the vicinity of the shelter directly into a melter can be unsanitary and quickly depletes the supply within a shovel's throw.

Modified feedbags with a flat polypropylene weave that holds snow well offer a useful container for snow collection. Placing the bag in the snow melter permits wetting of the snow inside through the weave, yet prevents debris from falling into the tank. The heat exchanger in the bottom of the snow melter proved to be an effective use of the engine's waste heat for melting.

Storage and distribution proved to be adequate by the second test season after working out a number of minor defects in the system. The primary means of distribution was Tygon tubing, polyethylene fittings and stainless steel hose clamps. Connections of these components sometimes leaked after exposure to extreme cold.

All valves were brass or stainless steel to pre-

vent problems with catching water and freezing. The "ball-valve" type proved to be satisfactory. The electric flexible impeller water pump had to have a metal housing to replace the freeze-vulnerable plastic one. Opening the cover plate to drain the inside was an essential step before freezing during the cold soak tests.

The water heater featured both heat recovery and electric heating elements. The heat recovery feature was very effective. The original 1200-W electric element was not powerful enough, but an 1800-W replacement proved satisfactory. Proper warning signs and a cotter pin on the electric switch to make its use more deliberate effectively diminished the likelihood of running the electric element with insufficient water in the tank.

The wastewater disposal system employed quick-disconnect attachment connections during the first season at CRTC. These were vulnerable to rusting and freezing. Screw-on insulated fittings and hoses replaced the previous arrangement. The CRTC reports did not discuss the success of the improvement.

Warm weather tests prior to the second test period indicated that the wastewater holding tank, which causes accumulated water to leave the shelter through an insulated hose, worked properly. This incorporates a syphon that drains the entire tank without further attention after a lever has depressed the top of the hose below the water level in the holding tank. The purpose of this feature is to prevent slow trickles of water from accumulating ice in the hose and causing blockage.

Shelter reliability

The CRREL shelter prototype proved to have a very reliable enclosing structure. Likewise, the supporting/mobility structure was reliable, marred by only two incidents, one significant but unnecessary. In 32 expansion/striking cycles at CRTC and many more at CRREL only the failure of the undercarriage during towing would have prevented delivery and setting up of the shelter. This structure probably would not have failed except for the incident resulting from the workman locking out the steering during preparation of the shelter. The ROC (U.S.A. TRADOC 1974) requirement, a mean-cycle-between-failure of not less than 24 movement cycles, was exceeded.

However, 49 failings of the shelter's equipment were reported during the two test seasons, 80% of which pertained to the installed equipment and more than half of these to the alternator set. Most of the problems with the alternator set would probably have prevented a crew in a remote location from being able to heat the shelter for more than a few hours with the available battery capacity to run the gasoline heater.

The next most vital problem was the performance of the auxiliary heater. Often this would have been unable to preheat the engine after a cold soak.

Possibly many of the problems with the engine and auxiliary heater would not have occurred during constant occupation because a crew would have kept those components from cold soaking. However, any crew in a cold, hostile environment would require total reliability from these components, especially on start-up.

Structure

Two important structural problems for military ISO shelters have been racking strength and panel delamination. The shelter's panel showed no signs of delamination under adverse weather conditions. However a panel racking test gave inconclusive results.

Panel delamination was not a problem in the CRREL prototype shelter. Unlike honeycomb construction typical of other shelter designs, the CRREL shelter construction employs redwood stiffeners separating the plywood skins. The stiffeners separate areas of extruded polystyrene insulation on 12-in. centers. The construction adhesives employed are very resistant to moisture damage.

Performance of other shelters

Other hard wall shelters tested at CRTC have not performed nearly as well as the CRREL prototype in terms of erection speed, crew productivity or ease of manipulation with arctic mittens.

CRTC had tested two Air Force Bare Base 3-for-1 expandable shelters of about 265-ft² floor area during the 1973-74 winter test season. The Air Force shelters (similar to the one in Fig. 15) incorporated add-on features including an arctic cover, vestibule and carpet for use in extreme cold. These items impeded ease of erection without adding very much in thermal performance.

The ROC criterion for a shelter of 265 ft² is 6.6 man-hours to erect or strike. The best average time recorded under winter conditions (Malone 1974) for the Air Force shelters was 8.3 man-hours, of which 2.2 man-hours was devoted to the arctic cover alone. Even with this item omitted from the erection sequence, fully two-thirds of the steps for erecting or striking this shelter

Figure 15. Three-for-one expandable hard wall shelter tested at CRTC 1973–1975.

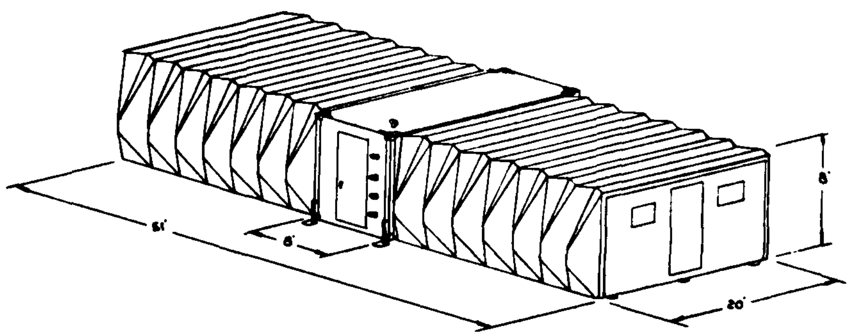


Figure 16. Expandable 50-ft ISO shelter tested at CRTC 1974–1975.

could not be performed when arctic mittens were worn. Some of the steps were not even possible when work gloves were used.

The following year CRTC tested an ISO shelter that expands to 50 ft with an accordion-like shell (Fig. 16). This shelter provides much space from one package, but at the expense of erection ease and thermal efficiency. The ROC criterion to erect the 925-ft² shelter is 23 man-hours. Winter testing at an average ambient temperature of -32°F required at least twice that erection time on the average.

The test officer summed up the test results for erecting the 50-ft shelter:

> The EXS was difficult and time-consuming to erect under arctic winter conditions. Hardware and component failures and difficult interfaces and connections of components caused operations to proceed slowly and with excessive caution to preclude damage to the EXS (Beavin 1975).

This comment is in contrast to the appraisal of the test officer for the CRREL prototype: "In general, except for difficulties encountered with the hydraulic jack, the shelter was easily deployed and struck at all temperatures" (Dollahite 1979).

Temperature stratification was a significant problem in shelters CRTC has tested previously. In the Air Force Bare Base 3-for-1 expandable

models the temperature difference between floor and ceiling was as great as 10°F at a ΔT of about 100°F (Malone 1974). The 50-ft expandable Air Force EXS shelter was even more prone to maldistribution of air temperature (Beavin 1975) with a vertical difference of up to 20.6°F and a horizontal difference of up to 26.2°F.

Tests of the Air Force Bare Base shelters revealed that the carpets and add-on covers did not contribute significantly to the thermal performance of the shelter envelopes.

The CRREL prototype required an investment in time to erect the optional tentage that was similar to that required with the Bare Base shelters for their special vestibule and arctic cover. However, the additional storage space and weather protection make the effort worthwhile in the case of the CRREL shelter.

CONCLUSIONS

The CRREL shelter prototype demonstrated self-reliance, ease of operation and thermal efficiency in most respects. The major disappointment was the generator set's lack of reliability. The shelter's performance demonstrates that the concepts it embodies are much better suited for use in extremely cold remote regions than the concepts in current shelter design. In particular, U.S. military planners should consider shelters with built-in mobility and pallets, simple-to-manipulate, robust field connections, good thermal design and heat recovery for space heating.

FUTURE STUDIES

The shelter prototype's qualities as an ISO shipping container are the greatest unknown of all the requirements stated in the military ROC document (U.S.A. TRADOC 1974). The important aspects are the shelter's ability to withstand a 100.8-kip load on each corner column, its racking resistance to a 35-kip load applied at any top corner and resisted at the diagonally opposite bottom corner, and its ability to resist a 660-lb load applied evenly over a 2 × 1-ft area on the roof. Most of these tests would require synergy from the entire shelter structure as well as resistance from the component directly subject to the load. Therefore testing a single panel from the shelter cannot be conclusive if it falls short of the mark. On the other hand, any failure while testing the complete shelter would probably be so sudden that the shelter would break before it was possible to withdraw the load. Testing should not be conducted on the CRREL prototype, because it has many years of use ahead of it before being subject to sacrifice.

Other significant tests that shelters must undergo to satisfy ROC requirements are dropping and wall strength. The Army (U.S.A. NARADCOM 1975) drops the shelter 12 in. on corners, edges and the entire bottom when loaded to its maximum gross weight. The walls should be able to accommodate fasteners with 2000-lbf tensile strength and 100 in.-lb resistance to torque.

These are important untested qualities. Certain aspects of the shelter design did not perform fully satisfactorily and need redesign and retesting:

1. The steering linkage failed during towing and caused progressive failure of the underpinnings.
2. The skis and wheels need more directional stability.
3. The legs should adjust to higher loading heights so that they can permit self-loading on a wider variety of vehicles.
4. The generator set was unreliable—diesel engines, standard military equipment and fuel cells should receive scrutiny for simplicity, reliability and efficiency in extreme cold.
5. The tentage needs minor adjustment to make it easier to erect when personnel are wearing arctic garb.
6. The snow melter requires some fine tuning and thorough field testing.

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